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TECHNICAL REPORT
69-62-CE

DEVELOPMENT OF A FIRE-RESISTANT AND RAIN-PROTECTIVE FABRIC

by
Robert Donnelly

Prodesco, Inc.
Perkasie, Pa.

Contract No. DAAG17-67-C-0181

December 1968

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing & Personal Life Support Equipment Laboratory
TS-161

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FOREWORD

This 15-month development activity was directed toward the goal of producing a finished fabric material that possessed the following design qualities:

(1) A maximum weight of 9 ounces per square yard, if double layered; both layers shall not total more than 9 ounces.

(2) A maximum of 10 cu. ft./sq. ft./min. of air permeability.

(3) Ability to withstand one inch/hour of rainfall for a period of 8 hours before and after five launderings.

(4) An after-flame time of 2.0 seconds (maximum) after 15 launderings.

(5) "Good" colorfastness to light after 20 Fade-o-Meter hours.

This final report is arranged according to specific areas of endeavor, such as: fiber investigation, yarn development, etc. This method was preferred to a "chronological" approach in order to help the reader find continuity to the program.

This work was authorized under Project No. 1J664713D547, Individual Combat Protective Clothing and Equipment Development.

CONTENTS

LIST OF TABLES

ABSTRACT

A three-phase program with the ultimate objective of developing a lightweight, flame-resistant, water-repellent, finished fabric is reported. A continuous filament Nomex fabric meeting all the design objectives was selected from 14 conceptual samples.

Phase I included an investigation of fibrous materials, a comparison of yarn blending techniques, fabric design and development of single and double layered prototypes, and physical testing of each sample submitted.

Phase II involved refining constructions and process details and applying a revised finishing procedure on all materials submitted. Commercial scale-up of the first prototypes was also an objective.

Phase III comprised the weaving and finishing of 1,000 square yards of the selected continuous filament Nomex fabric on a commercial production basis. Final evaluation of the filament Nomex fabric revealed that all of the design objectives were realized when converting from small to large-scale production except for providing the desired water resistance protection.

DEVELOPMENT OF A FIRE-RESISTANT AND RAIN-PROTECTIVE FABRIC

INVESTIGATION OF MATERIALS.

Prior to and in preparation for the yarn and fabric development portions of this study, an investigation of fibrous materials was conducted to assess and characterize materials available to the textile industry.

The primary requirement was a fiber with inherent, or add-on, flame-retardant properties. Other material requirements were ease of handling in textile manufacturing, good serviceability, and reasonable cost/performance properties.

All organic and inorganic fibrous materials were considered. Many were rejected because of failure to meet one or more of the stated requirements. The majority of organic textile fibers rejected could not qualify for the flame-retardant property. Certain "exotic" fibers, such as: Chromel-R*, stainless steel, carbon, and Teflon**, were rejected for reasons of extremely high cost or poor serviceability.

Nine fibers were considered initially. Of these, five fibers were used in the program, and the other four were not used for reasons stated in the following summary.

1. Nomex

Nomex** a high-temperature resistant polyamide fiber, is commercially produced in natural (egg shell) and solution-dyed olive green colors. A dyeable Nomex fiber will soon be available. Olive green Nomex was used for all fabrics, either 100 per cent or blended with other fibers. The favorable properties of Nomex include high-temperature resistance, permanent flame-retardant properties, excellent abrasion resistance, high strength, and ease of processing on textile equipment. The disadvantages of using Nomex are its high cost and poor ultra-violet resistance.

2. Fiber 101

This is a product of Monsanto Company Textile Division. The physical properties, advantages and unfavorable characteristics of the fiber are the same as Nomex. This fiber was not used in the program, but could be substituted for Nomex in any of the staple fiber fabrics. Fiber 101 is not available as continuous filament.

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*Registered trademark of the Hoskins Mfg. Company
**Registered trademark of the E. I. duPont de Nemours Co., Inc.

3. Modacrylic Fibers

Two modacrylic fibers were considered for this project. This class of fibers contains a large percentage (over one-half) of vinyl chloride, and is self-extinguishing through the release of chlorine gas upon combustion. Dynel, a product of Union Carbide Chemicals Corporation, was the modacrylic fiber selected. Verel, a product of Eastman Chemical Products, Inc., although not used, could be substituted in any of the fabrics that contain Dynel. The favorable features of modacrylic fibers are ease of processing on textile equipment, self-extinguishing properties, and availability as a shrinkable fiber to assist in closing fabric structures. However, it presents poor abrasion resistance, and shrinkage in flame.

4. Flame-Retardant Rayon

Two types of flame-retardant rayon, recently introduced in pilot quantities for evaluation purposes by FMC Corporation, American Viscose Division, were used. The first was semi-permanent, and the second was an improved permanent flame retardant with durable laundering properties. The advantages offered by a flame-retardant rayon are moisture absorbency for comfort, flame retardant incorporated into the fiber, low cost, and ease of processing on textile equipment. Adversely, the fiber has low strength, and poor abrasion resistance.

5. Fiberglas

The new ultra-fine diameter filament Fiberglas, designated as "Beta" by Owens-Corning Fiberglas Corporation, provides the advantages of nonflammability and low cost. However, Beta Fiberglas has poor abrasion resistance, low tearing strength, and high specific gravity.

6. Cotton

Flame-retardant treatments, such as Hooker Chemical Corporation's THPC Process for cotton, have been improved to the point where semi-permanency to laundering can be assured. The usefulness of cotton fiber is obvious due to its long use in military service. However, any flame-retardant treatment will degrade the strength properties of cotton fabrics.

7. Saran

Saran is a self-extinguishing fiber composed of at least 80 per cent vinylidene chloride. In addition to its self-extinguishing properties, it exhibits good ultra-violet resistance in solution-dyed form and good chemical resistance. It was not evaluated in this project because it is not available in this country in deniers suitable for clothing applications. Further unfavorable characteristics of the fiber are a low abrasion resistance, low melting temperature, and high specific gravity.

8. Vinyon HH

This fiber is manufactured with a high percentage of polyvinyl chloride as the fiber-forming substance. By itself, it will not support combustion. The fiber has very low strength and abrasion resistance and low melting temperature, and was not used for these reasons. Although it is self-extinguishing, it is cited here as a possible fabric-sealing medium because of its low melting temperature.

YARN MANUFACTURE.

The second unit of the investigative effort was concerned with the evaluation of yarn blending techniques. The results of the yarn manufacture investigation were to be a quantity of yarn usable in the next step, "Fabric Design and Manufacture."

1. Blended Yarns

The purpose of blending other fibers with Nomex was to alter the properties of 100 per cent Nomex fabric. Blending was considered in four different versions: intimate blend, roving blend, yarn plying, and core spinning.

The blend level used throughout the program was 50/50. This was decided upon as a standard so that the variable of blend levels would not be a factor. For blends other than intimate and core spinning, it is difficult to blend other than 50/50.

Blended yarns for Phase I were all spun on 18/1 cotton count. This size was picked to accommodate the yarn ply and core spun systems in which fine count commercial yarns were used. The

finest yarn available of Nomex is 37/1, and when used in a 50/50 blend, it resulted in an 18/1 yarn size.

a. Intimate Blending.[1] This system of blending yarns was used in Phase I and II. It was selected as the most versatile and acceptable method of blending fibers with Nomex for this program.

In producing intimately blended yarns, the fibers are first opened and thoroughly mixed, either by hand or mechanically. This mixture of fibers is then processed through a picker to further blend the fibers into a lap. The lap is carded and the card sliver is doubled on a drawing frame. Further blending takes place at the finish drawing and roving operation. The final spinning is accomplished by inserting two rovings into a single spinning spindle.

The blended yarn produced in Phase II was a 50/50 blend of Nomex and Permanently Flame Retardant Rayon in 22/1 and 18/1 cotton counts. Considerable difficulty in processing the yarns was experienced in this scale-up phase. The problem was primarily caused by high surface friction and static properties of the PFR Rayon which resulted in choking on the card and uneven sliver. This uneven yarn created problems in weaving later on. It was impossible to correct this problem in the spinning lab and the American Viscose Technical Department was consulted concerning this problem.

In later technical discussions with the American Viscose Division of FMC Corporation, a spinning lubricant was recommended. Unfortunately, due to timing, it was not possible to redo this blend study. Several looms have been observed in operation with yarns produced from properly lubricated PFR Rayon and it is felt that through further experimentation this should not present any problem.

b. Roving Blending. Yarns were made from two different rovings on the spinning frame, each produced in 100 per cent fiber form through the roving step. The uniformity of roving blend yarns is excellent. This process yielded a yarn that could be easily woven and had an appearance similar to a plied yarn. This system was not used for producing any yarns after Phase I.

c. Plying. Three plied yarns were produced during Phase I. The test results on fabrics woven from plied yarns were very poor. An exception to these results was the Beta/Nomex blended

[1] See Table I

fabric which did have good air permeability and strength properties. This fabric was coated with acrylic to close the interstices.

d. Core Spinning. The term "Core Spinning" applies to the process of spinning a staple yarn with two dissimilar materials, one comprising a central core around which the other fiber is spun. This is usually accomplished by feeding a prepared yarn, either continuous filament or staple, under the front roll or a yarn spinning frame. Commercial core spun yarns are spandex core/acrylic yarns used in fashion wear.

The parameters for spinning a yarn using this technique were: 50/50 blend level and yarn size of 18/1 cotton count. To achieve this, a 37/1 Dynol yarn was fed under the front roll of the spinning frame while spinning with a Nomex roving. The yarn had a spiral rather than a straight spun yarn appearance. In all cases, no matter what machine adjustments were made in the drafting zone or core yarn tensions, the core would not remain completely buried within the Nomex sheath.

No fabrics were made from this yarn. The core spinning technique was deferred for later study if blend levels of 75/25 or higher were to be used. This decision was made because: (1) the results were good from the intimate blending technique; (2) the large amount of development effort required to establish blending parameters of core spinning; and (3) the questionable economics of such a yarn spinning system compared to intimate blending.

TABLE I

BLENDED YARNS PRODUCED (PHASES I AND II)

Size (C.C.)	Description	Twist (T.P.I.)	Produced (lbs.)	Used For
18	50/50 Nomex/Dynel (Intimate)	17.7 Z	2.3	Trial
18	50/50 Nomex/Dynel (Roving)	17.7 Z	1.8	1C (W)[1]
18	50/50 Nomex (Sheath)/Dynel (Core)	17.7 Z	1.3	Not Used
18	37/1 Nomex and 37/1 Dynel (Plied)	10 S	1.8	Not Used
18	50/50 Nomex/Cotton (Intimate)	17.7 Z	2.3	Not Used
18	50/50 Nomex/Cotton (Roving)	17.7 Z	2.5	1H (W)
18	50/50 Nomex/Cotton (Roving)	12.7 Z	0.5	1H (F)
18	37/1 Nomex and 35/1 Cotton (Plied)	10 S	2.0	Not Used
22	450-1/0 Beta and 40/1 Nomex[2] (Plied)	10 S	-	1J (W & F)
18	50/50 Nomex/Dynel (Roving)	12.7 Z	0.3	1C (F)
18	50/50 Nomex/Rayon (Intimate)	18.8 Z	2.0	1G (W)
18	50/50 Nomex/Rayon (Intimate)	12.8 Z	0.5	1G (F)
22	50/50 Nomex/Rayon (Intimate)	16.0 Z	10.0	Trial
18	50/50 Nomex/Rayon (Intimate)	15.0 Z	2.0	Trial

1/ Sample code and yarn direction (Warp or Filling).

2/ Produced by Owens-Corning Fiberglas Textile Research.

2. 100 Per Cent Yarns

This term is used to describe yarns that were prepared for weaving and consisted entirely of one fiber type. These yarns were both staple and continuous filament.

a. Phase I. Five yarns of 100 per cent fiber were produced for Phase I. Table II lists these yarns, the quantities, twists, and use.

TABLE II

100 PER CENT YARNS PRODUCED FOR PHASE I

Size	Description	Twist (T.P.I.)	Produced (lbs.)	Used For
200 denier	200/100/3 Z olive green Nomex	3 Z	7.50	1A (W) 1B (W) 1E (W)
37/2	37/1 Nomex 2 ply	5 S	7.75	Trial
16/1	100% Type 183 Dynel	12 Z	1.25	1B (F) 1F (F)
22/1	100% Type 451 Nomex	18.8 Z	7.40	1D (W)
22/1	100% Type 451 Nomex	14.0 Z	1.0	1D (F)

There were no difficulties encountered in the processing of these five yarns.

b. Phase II. There were four 100 per cent yarns prepared for this phase. Table III lists these yarns, quantities, twists, and use.

Problems were again encountered with the PFR Rayon spinning. These problems were the same as reported previously in the blending program. Lack of time and material would not allow for a rerun to establish any improvement through use of a new lubricating procedure.

American Viscose has indicated that satisfactory yarns and fabrics are made on commercial equipment using this lubrication technique. The yarn had sufficient strength for use as filling in Item 20, Satin Weave.

TABLE III

100 PER CENT YARNS PRODUCED FOR PHASE II

Size		Twist (T.P.I.)	Produced (lbs.)	Used For
200 denier	200/100/3 Z olive green Nomex	3 Z	17	2C (W)
22/1	100% Type 451 Nomex	16.4 Z	20	2A (W & F) 2B (W) 2D (W)
18/1	100% Type 183 Dynel	12.7 Z	5	2B (F)
22/1	100% PFR Rayon	16.4 Z	5	2D (F)

c. Phase III. Production of 1,000 square yards of fabric selected for Phase III required twisting of 180 pounds of 200/100/0 Type 432 Nomex of the latest color, ultraviolet stabilized yarn. This yarn was twisted on a Fletcher, Model T-10 down-twister with 20 spindles. Experience with Nomex continuous filament yarn has shown that if "C" tension is applied to the untwisted yarns, looped or broken filaments are reduced to an acceptable level. The tension at the delivery side of the feed rolls was approximately 15 grams. This was accomplished by using a #22 size traveler and a spindle speed of 1250 rpm.

FABRIC MANUFACTURE

Weaving was selected as the method of fabric manufacture that would produce the most desirable fabric properties. To meet the physical characteristics outlined in the "design objectives," which included a maximum air permeability of 10 cubic feet per square foot per minute and a maximum weight of 9 ounces per square yard, other methods of fabric manufacture, such as knitting or non-woven process, were not evaluated.

The fabric development portion (Phases I and II) was separated into two studies: single-layer and two-layer fabrics. All single-layer fabrics but one were produced within the facilities of Prodesco. The exception is the Beta/Nomex fabric (Item 1J) which was supplied by Owens-Corning Fiberglas Corporation. Weaving in all three phases was performed on Crompton & Knowles' looms of either 4 x 4 Silk, W3 or S4 designation.

Several of the fabrics in Phase II should have been woven in a heavier loom than was available to Prodesco at the time. The fabric constructions were such that a "duck" type loom was necessary. Provisions were made for the installation of such a loom should the production portion (Phase III) require that the fabric be a "duck" type.

1. Single-Layer Fabrics

a. 100 per cent Filament Nomex. Using data generated in a U. S. Air Force contract, it was possible to determine the lightest weight fabric that would produce a finished air permeability of under 10 cubic feet. The air permeability test was considered to be a simple method of qualifying a fabric for further evaluation.

Table IV lists the air permeability results obtained under the Air Force contract.

TABLE IV

AIR PERMEABILITIES OF FILAMENT[1/] NOMEX FABRICS

Plain Weave, Various Twists

Permeability ($Ft^3/Ft^2/Min$)	Construction (W x F)	Twist (W x F)		Weight (oz/yd^2)
4.23	82 x 41	0	0	3.24
13.40	81 x 41	0	3	3.24
29.53	81 x 41	0	6	3.24
8.30	81 x 41	3	0	3.16
21.98	81 x 40	3	3	3.17
35.75	82 x 41	3	6	3.18
15.20	80 x 42	6	0	3.29
33.28	80 x 42	6	3	3.24
43.18	80 x 42	6	6	3.27

[1/] 200/100 Olive Green Nomex
Contract F33657-67-C-0078

The first fabric in the table shows a permeability of 4.23. This construction was not used because "0" twist Nomex warp yarn is extremely difficult to weave. The fabric with a construction of 81 x 41 (3 turns per inch warp, 0 turns per inch filling) had an air permeability of 8.30. To assure that this permeability would be more permanent to laundering and wear, the fabric construction was increased. A warp was prepared using 200/100/3Z, Type 432 Nomex, at 100 ends per inch (50 dent reed, 2 ends per dent).

Two samples were woven. The first sample was woven with 77 picks per inch of 200/100/0, Type 432 Nomex with a 2 x 2 right-hand twill weave. A second sample was woven with 58 picks per inch using the same yarn, but with a 2 x 1 oxford weave.

These samples were scoured and heat set, then tested for air permeability. Sample #2 was chosen as a candidate material and submitted as Item 1A in Phase I. The finishing procedures used on this and all fabrics are discussed in Section D, Fabric Finishing.

After the U. S. Army Natick Laboratories evaluated Item 1A, a request was made to submit another sample which would exhibit more balanced tensile strength properties.

The warp was made of 200/100/3Z, Type 432 Nomex at 88 ends per inch (44 dent reed, 2 per dent). It was woven in a Crompton & Knowles "S" loom at 43.2 inches reed width, using "0" twist filling yarns at 60 picks per inch in an oxford weave. The pickage was maximum for this type of yarn and weave, but was not beyond the capacity of the loom. The fabric was finished as required and submitted as Item 2C in Phase II. It exhibited the lowest air permeability (1.57 cu.ft./sq.ft./min.) of any fabric produced in the contract. The strength properties were more closely balanced (13 pounds warp, 11 pounds fill tearing strength). This item was selected for final prototype production because of the "rain room" performance (Section V).

As described in the Yarn Manufacture, Section II, 180 pounds of 200/100/0 Olive Green Nomex, Type 432 (color 5) was twisted with 3 turns per inch Z for the warp. Two warp beams were prepared at 88 ends per inch, 50 inches wide, 465 yards long. These warps were drawn in a straight draw on an 8 harness and woven in a Crompton & Knowles "S-4" (4 x 1) box loom. Greige fabric produced was 880 lineal yards or 1,170 square yards. There were no weaving difficulties encountered in this production run. Most fabric defects were traceable to the inherent quality of continuous filament Nomex.

b. 100 Per Cent Staple Nomex. In the Air Force contract mentioned previously, a parallel study was conducted to determine air permeabilities of fabrics constructed of "spun" Nomex yarns. These fabrics were woven in a Crompton & Knowles "C" type loom, and the lowest permeability achieved was 39.8 cubic feet on the last fabric item in Table V.

TABLE V

AIR PERMEABILITIES OF STAPLE[1] SPUN NOMEX FABRICS

Permeability ($FT^3/Ft^2/Min$)	Construction (W x F)	Yarn Size (W x F)	Weave Pattern	Weight (oz/yd^2)
55.56	144 x 90	37/1 x 37/1	HBT	5.14
63.85	144 x 86	37/1 x 37/1	HBT	4.90
83.50	146 x 65	37/1 x 37/2	HBT	5.72
70.30	145 x 70	37/1 x 37/1	Twill	4.70
102.00	144 x 64	37/1 x 37/1	Twill	3.90
49.3	124 x 73	23/1 x 23/1	HBT	6.89
67.0	120 x 52	23/1 x 23/1	Twill	6.59
43.1	120 x 44	23/1 x 23/1	P. W.	6.07
39.8	120 x 40	23/1 x 37/2	P. W.	6.22

[1] Commercial Yarns used in Air Force Study.

To establish certain basic fabric parameters, a simple study was first conducted using 2-plied commercial (37/1) Nomex yarns. The desired weight of 4.5 ounces per square yard for a single-layer fabric, as stated in the "Design Objectives," denotes a construction must be 115 total yarns (warp and fill) per square inch.

A warp was made at 72 ends per inch (36 dent reed; 2 per dent), and 47 picks plain weave. Air permeability tests on these and heavier fabrics showed that the construction was too open. The warp was re-reeded to 84 ends per inch with a 28 dent, 3 per dent. Two samples were woven in satin weaves in order to place as many picks per inch into the fabric as possible.

The test results on both fabrics showed that these attempts did not reduce air permeability to an acceptable level. Table VI lists the fabrics discussed, their constructions, and air permeabilities produced.

TABLE VI

100 PER CENT 2-PLY STAPLE YARNS SINGLE-LAYER FABRICS
(FINISHED HEAD END TESTS)

Sample No.	Weave	Construction (In Loom)	(Finished)	Weight (oz/yd^2)	Air Permeability ($ft^3/ft^2/min$)
1	Plain	72 x 47	74 x 48	4.67	59.5
2	2/2 Twill	72 x 62	77 x 62	5.39	63.7
3	4 H Satin	72 x 62	77 x 68	5.21	61.5
4	4 H Satin	84 x 54	88 x 52	5.30	99.0
5	8 H Satin	84 x 70	88 x 74	5.79	141.0

A new fabric series was constructed using 22/1 cotton count yarns described in Yarn Manufacture, Section II. The warp for these fabrics was made at 120 ends per inch in a 30 dent reed, 4 ends per dent. Two samples were woven: one plain and one 2 x 1 oxford, both at 40 picks in the loom. Table VII lists the samples and their test results. Sample 2 was selected for submission and was woven 7 yards long finished, and submitted as Item 10 in Phase I.

TABLE VII

100 PER CENT STAPLE YARNS SINGLE-LAYER FABRICS
(FINISHED HEAD END TESTS)

Sample No.	Weave	Construction (In Loom)	(Finished)	Weight (oz/yd^2)	Air Permeability ($ft^3/ft^2/min$)
1	Plain	120 x 40	123 x 42	5.25	28.0
2	(2 x 1) Oxford	120 x 40	123 x 41	5.01	26.4

After evaluation of the staple fabric, the U. S. Army Natick Laboratories recommended that certain changes be made in the fabric construction for Phase II. Sufficient 22/1 cotton count, 100 per cent Nomex, Type 451, yarn was prepared to make a warp of 120 ends per inch, 49 inches wide. The crimping of the filling yarn was planned to reduce the fabric width so that the warp construction would be approximately 126 ends per inch finished. The finished package was to be 50 per inch.

It was not possible to weave more than 41 picks per inch in the loom on this fabric. Weaving was done in a Crompton & Knowles W-3 Loom, which at the time was the heaviest loom at Prodesco. Because of this weaving problem, considerable delays were encountered and a properly constructed fabric could not be made. A Draper X-P Loom was installed at Prodesco in the event the yardage requirement for Phase III would be a fabric similar to this. This loom is capable of weaving heavy canvas-type fabrics. The finished construction of this item, submitted as Item 2A in Phase II, was 122 x 43.

c. Ortho Blend Fabrics. Ortho blended fabrics are those which are comprised of two different yarns. They are constructed so that one yarn is used in the warp and the other in the filling. In all cases, the warp was Nomex and the filling was composed of other fibers.

(1) Nomex Staple Warp/Dynel Staple Filling. The staple Nomex warp that was used for Item 1D (100 per cent Nomex Staple Fabric) was also used as an evaluation for the effect of fabric closing, using high-shrink Dynel filling yarn. A sample was woven with an oxford weave at 40 picks per inch, using a 16/1 count with a 3.0 twist multiple, high-shrink Dynel filling yarn. The sample was finished and tested for air permeability, which was satisfactory at 6.35 cu.ft/sq.ft/min. This fabric was submitted as Item 1F in Phase I.

The U. S. Army Natick Laboratories requested that this fabric be resubmitted under Phase II for further evaluation. The warp for Item 2A (100 per cent Nomex staple oxford fabric) was used for this fabric. The filling was an 18/1 count with 3.0 twist multiple, 100 per cent high-shrink Dynel. The maximum weaveable pickage was 38 picks per inch in the W-3 Loom. Again, the disadvantage of not having a "duck" type loom was demonstrated in this fabric. Finishing closed the warp considerably, and the air permeability which resulted was 8.0 cu.ft./sq.ft./min. This fabric was submitted as Item 2B in Phase II.

(2) Nomex Filament Warp/Dynel Staple Filling. A parallel study to the staple warp was conducted in Phase I using the filament warp from Item 1A. The in-loom construction was 100 ends per inch (50 dent reed, 2 per dent) of 200/100/3Z, Type 451 Nomex. The filling used was 18/1, 100 per cent Type 183 high-shrink Dynel with a 3.0 twist multiple. The pickage was 46 per inch. A head end was finished and tested for air permeability which was acceptable at 6.8 cu.ft./sq.ft./min. Yardage was woven, finished and submitted as Item 1B. No further work was done on this concept.

(3) Nomex Staple Warp/PFR Rayon Filling. Phase II had an additional Ortho blended fabric included. It was designed to be a "two-sided" fabric, using the Nomex staple warp as the face and PFR Rayon filling as the back. The same warp used for Items 2A and 2B was woven in a 4-harness satin "crowfoot" weave at 59 picks per inch in the loom. The filling yarn was a 22/1 100 per cent PFR Rayon with 3.5 twist multiple. There was little difficulty weaving this fabric, but quality was poor because of unevenness of the PFR Rayon yarn. This fabric was finished at American Viscose and submitted as Item 2D in Phase II.

d. Blended Fabrics. The "Fabric Manufacturing" portion of the blending study has as its objectives the comparison of yarn-blending techniques described previously, and also the comparison of yarn blends with ortho blends. In yarn-blended fabrics, the fibers are distributed in a more uniform array than with the orientation of warp versus fill in ortho blended fabrics. The four different yarn-blending approaches: intimate, roving, ply and core spin are discussed in relation to fabrics produced.

(1) Nomex/Dynel. This portion of the Yarn Blending Program was used as the preliminary evaluation for all four blending concepts. Through fabrication studies on the core spun yarn concept, the decision was made not to produce core spun yarns until different blend levels were decided upon. Details of the problems involved in the core spinning study are discussed in Yarn Manufacture, Section II.

The first fabric of this series was constructed with the intimate blended yarn, an in-loom construction of 70 ends per inch (35 dent reed, 2 ends per dent), and various pickages and weaves. Three samples were selected for head end finishing and evaluation. Table VIII lists the samples and the test results.

TABLE VIII

50/50 NOMEX/DYNEL INTIMATE BLENDED FABRICS
(FINISHED HEAD END TEST)

Sample	Weave	Construction In Loom	Construction Finished	Weight (oz/yd^2)	Air Permeability ($ft^3/ft^2/min$)
1	1 x 1 Plain	70 x 44	88 x 57	6.85	51.2
2	2 x 1 Oxford	70 x 44	88 x 55	6.62	84.0
3	2 x 2 Twill	70 x 58	91 x 80	8.27	41.1

The head and finishing and testing showed unacceptable air permeabilities and fabric evenness. The head ends puckered badly during the finishing which may be an indication of an uneven yarn blend. This problem was reviewed to determine if any improvement could be made by redoing the intimate blended yarn. The quantity of materials being scheduled for this portion of the program could not assure that another lot would be more even. A decision was made to construct fabrics from roving blended yarns before respinning any intimate blended material.

This fabric was constructed in loom at 78 ends per inch (39 dent reed, 2 ends per dent). Two samples were woven with maximum pickage on both weaves. Table IX lists the finished head ends, their constructions, and test results.

TABLE IX

50/50 NOMEX/DYNEL ROVING BLENDED FABRICS

Sample	Weave	Construction In Loom	Construction Finished	Weight (oz/yd^2)	Air Permeability ($ft^3/ft^2/min$)
1	1 x 1 Plain	78 x 40	92 x 55	7.40	54.4
2	2 x 2 Twill	78 x 54	90 x 73	8.12	48.5

Less puckering appeared in these fabrics and the shrinkage was such that this blending technique was concluded to be as effective as intimate blending. Although the shrinkage was good, high air permeability was still present. This problem prompted further investigation of fabric shrinkage.

Another series of samples were woven to verify the shrinkage test and the same results were obtained. The fabrics were examined with a microscope. The Dynel fiber shifted to the inside of the yarn during fabric shrinking. This caused the Nomex, which is a "non-shrink" fiber, to crimp considerably. Discussions of this observation with Union Carbide Corporation's Technical Department confirmed that this effect is similar to that of "Turbo" Orlon yarns, i.e., fabrics with differential shrinkage blended into the yarns not only shrink upon finishing but also bulk considerably.

A check of fabric thickness in greige versus finished showed an increase of 33 per cent after finishing. This increase in thickness is indicative of fabric bulk. Without complicated finishing processes involving smoothing, calendering and possibly a coating, the air permeability of a blended fabric using differential shrinkage fibers cannot be substantially reduced. Sample 2 was woven six yards long, finished, and submitted as Item 1C under Phase I. The air permeability and bulking problems eliminated further work on the concept of blending Dynel and Nomex.

(2) Nomex/Cotton. Of the three yarns spun from Nomex and cotton, the roving blended yarn was selected for the first fabrication trial. At this point, plied yarns were no longer considered because of the previous experience with Nomex.

The intimate blended Nomex/cotton yarn was not used because it was uneven.

The fabric was constructed with 86 ends per inch (43 dent reed, 2 ends per dent). Two samples were woven: one plain weave and one 2 x 2 twill. The samples were finished and tested for air permeability. Table X lists the samples and their test results.

TABLE X

50/50 NOMEX/COTTON ROVING BLENDED FABRICS
(FINISHED HEAD END TESTS)

Sample	Weave	Construction In Loom	Construction Finished	Weight (oz/yd^2)	Air Permeability ($ft^3/ft^2/min$)
1	Plain	86 x 48	90 x 57	5.85	26.3
2	Twill	86 x 62	92 x 68	6.48	51.3

The plain weave was lighter in weight and had lower air permeability than the twill. This fabric was woven 7 yards long. Three yards were finished with flame-retardant treatment, as described in the Finishing Section, and submitted as Item 1H. No further work was done on Nomex/cotton blends.

(3) Nomex/Flame-Retardant Rayon Blends. The flame-retardant rayon fiber used in Phase I fabric was designated SPFR by American Viscose. SPFR represents semi-permanent flame retardency, that is, subject to removal by laundering. Two intimate blended yarns were spun to 22/1 cotton count; warp yarn was 4.0 twist multiple and filling was 3.0 twist multiple. The warp was constructed with 112 ends per inch in loom (28 dent reed, 4 ends per dent). Two samples were woven: one plain weave and one oxford at 32 picks maximum. Table XI lists these fabrics and their finished head end air permeabilities.

TABLE XI

50/50 NOMEX/FR RAYON INTIMATE BLENDED FABRICS
(FINISHED HEAD END TESTS)

Sample	Weave	Construction In Loom	Construction Finished	Weight (oz/yd^2)	Air Permeability ($ft^3/ft^2/min$)
1	Plain	112 x 32	114 x 37	5.74	71.0
2	Oxford	112 x 32	118 x 37	5.82	46.7

Either plain or oxford weave will yield the lowest air permeability per given fabric weight as proved by samples manufactured up to this point. A comparison of the two weaves indicated that the oxford weave was lower in air permeability, and this sample was selected for submission in Phase i as Item 1G.

Nomex/Flame-Retardant Rayon blend was selected for additional fabric evaluation in Phase II. The blend level was to remain at 50/50, but the yarn size and fabric construction were changed from the Phase I fabric. The rayon used in Phase II was designated PFR, meaning Permanent Flame-Retardant. This time the problems noted in the Yarn Spinning Section were present and the difficulties of weaving fabric from these poor quality spun yarns could not be overcome. The warp for this fabric was constructed 120 ends per inch in loom (30 dent reed, 4 ends per dent), 40 inches wide. Extreme difficulties in weaving a fabric of acceptable quality restricted the experiment to evaluation of the dyeing and finishing properties by American Viscose. Two samples were eventually woven: one an oxford using 22/1 cotton count filling at 40 picks per inch and the other using 18/1 cotton count in a 2 x 2 Twill at 44 picks per inch. These fabrics were neither tested nor submitted as candidate samples in this contract.

(4) Nomex/Beta Glass. The production of ply blend yarn and fabric was done by the Owens-Corning Fiberglas Corporation. The construction in loom was 80 ends per inch (20 dent reed, 4 ends per dent), and 80 picks per inch woven in a 2 x 2 lefthand twill. Owens-Corning's Technical Staff indicated that there was no problem in producing several hundred yards of this fabric. This fabric was submitted under Phase I as Item 1J.

2. Two-Layer Fabrics

All two-layer fabrics were constructed of continuous filament Nomex. The objective was to simulate 2 plies of a 4.5 ounce fabric in which each layer was to act as a moisture barrier, but bound together in such a way that the total structure resembled a single-layer fabric in all other characteristics.

A warp was constructed at 200 ends per inch, approximately 24 inches wide (50 dent reed, 4 per dent). Many weave designs were tried and rejected until a satisfactory, intimately bound, two-layer fabric was constructed. In addition to this fabric, another construction known as "waffle" weave was made. This specific weave was

developed for special flame-retardant, two-layer fabrics by Prodesco for the U. S. Naval Air Development Center, Johnsville, Pa. The "waffle" weave has areas where the two fabric layers are separated and create an air pocket within the fabric structure. This adds flame protection by virtue of the insulating value of the air pocket.

A comparison of the two weaves showed identical properties of weight and air permeability. Table XII lists the two fabrics.

TABLE XII

100 PER CENT FILAMENT NOMEX TWO-LAYER FABRICS

Sample	Weave	Construction In Loom	Construction Finished	Weight (oz/yd^2)	Air Permeability ($ft^3/ft^2/min$)
4	Waffle	200 x 92	203 x 98	7.99	8.5
5	Intimate	200 x 92	203 x 97	7.99	7.0

The intimately bound fabric was chosen because of its smoother surface appearance. This sample was woven, finished and submitted as Item 1E. A small piece of the "waffle" weave was submitted as an example for evaluation.

The U. S. Army Natick Laboratories requested that the intimately bound fabric be reproduced for Phase II. This required the production of two warp beams to be drawn in at a total of 200 ends per inch in the loom. The construction was plain weave top and bottom fabrics with an intimate binder repeated on each end.

During warping, a portion of one beam was damaged which made it impossible to weave any yardage at all. This beam was removed from the loom and the other beam was rereeded to the construction necessary for weaving Item 2C (single-layer, 100 per cent filament Nomex). While this fabric was being woven, two new beams were made in an attempt to weave the two-layer fabric again.

These warps were set up in the same loom and the head end woven. The construction was acceptable from the head end tests and

the yardage was started. The high number of ends per inch and the susceptibility of Nomex to filament breaking caused several bad areas of warp to develop. These were started by a loose filament trapping several yarns and breaking those filaments, an occasionally roughened loom part, such as a heedle or reed wire, would also begin damage. The fabric had become so difficult to weave that the warp had to be pulled ahead several times and weaving started over. Sufficient fabric was eventually woven and finished to be submitted as Item 2E in this phase.

When Item 2E was submitted, it was proposed to the U. S. Army Natick Laboratories that an increase in warp twist may be required before any quantity of this fabric could be produced.

FABRIC FINISHING

The U. S. Army Natick Laboratories presented recommended finishing procedures for fabrics in Phase II and Phase III. These are different from the finishing procedure used in Phase 1; therefore, they will be reported separately.

1. Phase I Finishing

The most difficulties were encountered in finishing the Nomex/FR Rayon and Nomex/cotton fabrics. The flame-retardant rayon was susceptible to loss of that property through finishing. The cotton blend fabric had severe color change because of the THPC treatment. Application of the THPC also caused a strength loss.

a. 100 Per Cent Nomex Fabrics. All fabrics consisting of 100 per cent Nomex fibers, either in staple or continuous filament form, were finished in the following manner:

(1) Scour in a beck at boil for 90 minutes to remove all processing sizes and oils and completely relax the material (lg/l of TSPP solution).

(2) Dry relaxed on tenter frame at 300°F.

(3) Heat set (relaxed) at 550°F. for one minute. This is the heat-setting temperature recommended by Dupont for processing of 100 per cent Nomex fabrics. Normally, Nomex will shrink from one-half to one per cent of its length in a relaxed heat-set condition. Heat setting relaxed is

an attempt at closing the Nomex fabrics to the maximum degree possible.

(4) Treat with ZePel* water repellent. This consists of passing the fabric through a solution (6 per cent ZePel B, 3 per cent Phobotex FTC, and 0.75 per cent Catalyst RB); padding with sufficient roll pressure to produce approximately 40 per cent wet pick-up; drying the fabric at 240°F. on the tenter frame; and a final cure at 325°F. for 2 minutes. A spray rating of 90-100 was observed on all 100 per cent Nomex fabrics submitted as a portion of Phase I.

b. Nomex/Dynel Blended Fabrics. All fabrics containing either blended yarns of Nomex and Dynel or Dynel filling in Nomex warp were treated in the following manner:

(1) Scour in a beck at boil for 90 minutes. This process was recommended by the Textile Fibers Department of Union Carbide Corporation for the complete relaxation and shrinkage of Type 183, high-shrink Dynel.

(2) Dry on tenter frame at 240°F. relaxed. All temperatures were kept no higher than 260°F. to insure that the Dynel component would not degrade.

(3) Treat with ZePel* water repellent. The fabrics were dipped in the solution as described above for 100 per cent Nomex. They were padded with sufficient roll pressure to allow 40 per cent wet pickup, dried at 240°F., and cured at 260°F. for 3 minutes. The longer cure time on these fabrics was necessary to compensate for the decrease from the normal 325°F. curing temperature. Spray ratings of 90 to 100 were observed on all fabrics treated in this manner.

c. Nomex/Cotton Blended Fabric. This fabric was finished as follows:

(1) Scour in a beck at boil for 30 minutes.

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* E. I. duPont de Nemours Co., Inc.

(2) Dye the cotton to match the Nomex using the following direct cotton dye formula:

1.25%	Solantine	Yellow	4 RL
0.50%	Solantine	Blue	6 GKS

(3) Treat with Hooker THPC resin. The treatment involves a lengthy procedure which is proprietary to the Hooker Chemical Corporation. The details of this process will not be related here, except to say the resin system used was #4, and the formulation was #34. This process degraded the dyestuffs on the cotton and caused a severe yellowing of the fabric. Hooker Chemical Corporation recommends that cellulosic fibers be dyed using the vat-dyed process, preferably dyed in yarn form.

(4) Treat with water repellent. A sample of THPC-treated fabric was immersed in an 8 per cent solution of Impregnole FH padded to a 50 per cent wet pickup, dried at 250°F. and cured at 300°F. for 60 seconds. Another sample was treated with the ZePel formulation as on the Nomex, dried at 240°F. and cured at 325°F. for two minutes. Both fabrics performed satisfactorily in spray tests and the ZePel treatment was used to complete the finishing on the cotton fabrics.

d. Nomex/Flame-Retardant Rayon Blended Fabric. Initial laboratory tests for finishing and dyeing procedures indicated that normal scouring and dyeing temperatures could not be used without the loss of the flame-retardant properties of the rayon. Several laboratory studies were made. The following process was determined to be the most practical:

(1) Scour in a beck at 160°F. for 30 minutes. The low temperature and short duration were sufficient to remove the processing materials while still retaining the flammability properties of the rayon.

(2) Dye the rayon to match the Nomex. The dye formulation consisted of 1.25 per cent Solantine yellow 4RL, 0.5 per cent Solantine blue 6GKS, 0.15 per cent Solantine brown 9RL, 20 per cent Glauber salts. The dyeing bath pH was 7. The dye bath was raised to 180°-190°F. for one hour. The fabric was tested for flammability after dyeing and was satisfactory.

(3) Treat with ZePel water repellent. The same formulation used for the 100 per cent Nomex fabric was used for this fabric also. Wet pickup was approximately 50 per cent. The fabric was dried at 220°F. for one minute, and cured at 240°F. for four minutes. Tests, after the ZePel treatment, showed the flammability was still satisfactory and the spray rating was over 90.

2. <u>Phase II Finishing</u>

As recommended by the U. S. Army Natick Laboratories for the authorization of Phase II, all fabrics submitted were finished according to the procedure below. Some variations were made and are discussed according to fiber content.

NATICK-RECOMMENDED FINISHING PROCEDURE

Formula BD-2 (Based on 60 per cent wet pickup)	Per Cent Add-on
5.0% Diisocyanate 1410 (100% solids)	3.0
0.5% Igepal CO-630	
13.0% ZePel B (13.4% solids)	1.0
13.4% Stanax (50% solids)	4.0

Preparation of the Mix (NLABS-Suggested Method)

Bath #1

The Diisocyanate 1410 and Igepal CO-630 (General Analine & Film Corp.) are combined with high-speed stirring. After thorough mixing, half the water (tap water) is added slowly with high-speed agitation. The Dupont ZePel B is then slowly added and the mixture stirred slowly until uniform.

Bath #2

In another container, the remaining water is used to solubilize the Stanax and sodium bicarbonate. Ten per cent of sodium bicarbonate, based upon the weight of Stanax, is dissolved in water and added to the Stanax. Bath #2 is slowly added to Bath #1 with moderate agitation.

Application

Application by padding is recommended, followed by drying at 250°F. and curing at 350°F. for three minutes. Following the curing, the fabric is after-washed at 140°F., rinsed at 100° to 120°F., squeezed and dried at 300°F. to 320°F.

a. 100 Per Cent Nomex Fabrics. All fabrics containing 100 per cent Nomex, either continuous filament or staple, were prepared for the recommended finishing procedure as follows:

(1) Scour in a beck at a boil to remove sizing and oils.

(2) Heat set relaxed at 550°F. for one minute.

(3) Treat with combination ZePel B and Stanax.

b. Nomex/PFR Rayon Blended Fabrics. Both the ortho and the intimate blended fabrics were dyed and finished at the facilities of American Viscose. They were scoured and dyed on a jig, using direct dye-stuffs on the PFR Rayon to match the Nomex. There was no problem in preparing or applying the water-repellent treatment. This demonstrated the compatibility of the treatment with commercial procedures.

The intimate blended fabric was not submitted to the U. S. Army Natick Laboratories because of numerous defects and poor fabric properties. The ortho blended fabric was submitted as Item 2D.

c. Nomex/Dynel Ortho Blended Fabric. In preparing this fabric for the finishing procedure, the process was modified to keep the curing temperatures under 260°F. To do this, the curing time was increased four minutes and the drying temperature was reduced. The preparation was done in the following manner:

(1) Scour in a beck at boil for 90 minutes.

(2) Dry on tenter frame at 240°F.

(3) Treat with combination of ZePel B and Stanax.

3. Phase III Finishing

The 1,000 square-yard production run of single-layer filament Nomex was finished at Bradford Dyeing Association, using the following finishing procedure recommended by the U. S. Army Natick Laboratories for Phase III:

a. Scouring - The fabric was desized and scoured in the conventional manner by Bradford Dyeing Association. Drying was performed on a 90-foot clip frame.

b. Heat Setting - The heat setting was performed in an autoclave by removing the air with a vacuum pump and then running in steam at 30 pounds per square inch for 20 minutes. The steam was then cut off and a vacuum produced for another 5 minutes. The steaming was again performed for 20 minutes, followed by another vacuum for 5 minutes. Care must be taken to avoid the presence of creases in the cloth since autoclaving would permanently set them in the fabric.

c. Combined Anti-static/water and Oil-Repellent Finish - The cloth was given a combined anti-static/water and oil-repellent finish. The combined anti-static/water and oil-repellent finish was prepared as follows:

(1) Prepare a solution containing 5.5 per cent Diisocyanate 1410, 0.55 per cent Igepal CO 630. Mix both chemicals with high-speed stirring and dilute with water by hand-stirring the latter to prevent foaming.

(2) 14.3 per cent ZePel B. Dilute with water.

(3) 14.7 per cent Stanax; 1.4 per cent sodium bicarbonate. Dilute both chemicals separately and add bicarbonate to the Stanax very slowly. Considerable foaming can be expected.

(4) Add (2) to (1) with gentle hand-stirring, then add (3) to the combined (1) and (2) solutions.

(5) The fabric is padded in a single bowl pad with reduced pressure to increase the wet pickup.

(6) The fabric is dried at 250°F. and cured at 350°F. for three minutes, followed by an after-wash on a six-bowl, continuous washer with the first bowl, containing 0.25 per cent Nonionic wetting agent, set at 160°F. The second and third bowls, with water only, were set at 160°F. The fourth, fifth and sixth bowls were set at 140°F., 120°F., and 120°F. Final drying is to be performed at 95 yards per minute on cans with an initial temperature of 350°F. and final can temperature of 200°F.

(7) The above formulation is based upon 60 per cent wet pickup.

FABRIC TESTING

Six tests were made on all greige and finished fabrics submitted to the U. S. Army Natick Laboratories. All testing was done in accordance with Federal Testing Specification, CCC-T-191b. All tests, except tearing strength and color fastness to light, were performed in Prodesco's testing laboratory.

Qualification testing of the Phase I fabrics was primarily air permeability. This test was considered as the simplest method for fabric qualification to meet the design requirements. Fabric thickness and shrinkage tests were used on occasion.

Each test procedure is discussed below with specific comments regarding any unusual fabric performances.

1. Weight of Cloth [1/]

Test Method 5041 (Weight of Cloth, small specimen method) was used. In this test, a piece 8 inches x 8 inches is cut from each specimen and weighed on a grain scale. The reading in grains is converted into ounces per square yard by the following formula:

$$0.0463 \times \text{Sample Wt. in Grains} = oz/yd^2$$

2. Air Permeability [2/]

This test was used to screen preliminary samples and was also conducted on greige and finished fabrics submitted to the U. S. Army Natick Laboratories. The test method used was 5450 (Permeability to Air-Calibrated Orifice Method). All tests were conducted at 0.5 inches water pressure on a Frazier air permeometer. Almost half of the fabrics submitted did not exhibit air permeabilities under the designated maximum of 10. Items 2A and 2D could have been woven heavier in correct loom. The most impressive air permeability figure is that of the single-layer filament fabrics, Items 1A, 2C and 3.

1/ Table XIII

2/ Table XIV

TABLE XIII

WEIGHT IN OUNCES PER SQUARE YARD
(METHOD 5041 - SMALL SPECIMEN METHOD)

Item	Description of Fabric	Greige	Finished
1-A	Single-layer filament Nomex	4.4	4.5
1-B	Filament Nomex warp/Dynel fill	5.5	6.5
1-C	50/50 blended Nomex/Dynel	6.0	8.0
1-D	Single-layer staple Nomex	4.6	6.0
1-E	Two-layer filament Nomex	7.4	8.0
1-F	Staple Nomex warp/Dynel fill	6.5	7.7
1-G	50/50 blend Nomex/FR Rayon	5.9	5.9
1-H	50/50 blend Nomex/cotton	5.7	6.7
1-J	Beta Glass/Nomex	4.7	5.8
2-A	Staple Nomex Oxford	6.4	6.4
2-B	Ortho Nomex Warp/Dynel fill	6.8	7.4
2-C	Single-layer filament Nomex	4.3	4.6
2-D	Ortho Nomex Warp/PFR Rayon fill	7.3	7.0
2-E	Two-layer filament Nomex	8.85	9.3
3	Single-layer filament Nomex	4.13	4.31

TABLE XIV

AIR PERMEABILITY (CUBIC FEET/SQUARE FOOT/MINUTE)
(METHOD 5450 - CALIBRATED ORIFICE METHOD)

Item	Description of Fabric	Greige	Finished
1-A	Single-layer filament Nomex	18.0	9.0
1-B	Filament Nomex warp/Dynel fill	42.0	6.8
1-C	50/50 Blended Nomex/Dynel	152.0	61.6
1-D	Single-layer staple Nomex	56.0	28.6
1-E	Two-layer filament Nomex	5.6	4.0
1-F	Staple Nomex warp/Dynel fill	16.5	7.8
1-G	50/50 blended Nomex/FR Rayon	51.8	49.2
1-H	50/50 blended Nomex/cotton	56.0	22.0
1-J	Beta/Nomex	92.0	7.0
2-A	Staple Nomex Oxford	12.9	15.1
2-B	Ortho Nomex warp Dynel fill	27.0	8.0
2-C	Single-layer filament Nomex	2.1	1.6
2-D	Ortho Nomex warp PFR Rayon fill	17.7	21.1
2-E	Two-layer filament Nomex	3.5	2.5
3	Single-layer filament Nomex	2.5	2.4

3. Yarns Per Inch[1/]

All fabrics, both greige and finished, were examined for the number of yarns per inch. Test Method 5050.1 was used - up to three inches counted in each dimension. The two-layer filament fabrics, Items 1E and 2E, had to be unravelled to determine the number of yarns per inch.

[1/] Table XV

TABLE XV

YARNS PER INCH
(METHOD 5050.1)

Item	Description	Greige	Finished
1-A	200/100/3Z Nomex Warp	108	112
	200/100/0 Nomex Filling	58	59
1-B	200/100/3Z Nomex Warp	108	130
	16/1 3.0 t.m. 100% T-183 Dynel Filling	47	48
1-C	18/1 50/50 4.0 t.m. Nomex/Dynel Warp	81	92
	18/1 50/50 3.0 t.m. Nomex/Dynel Filling	59	68
1-D	22/1 100% 4.0 t.m. Nomex Warp	121	123
	22/1 100% 3.0 t.m. Nomex Filling	40	41
1-E	200/100/3Z Nomex Warp	200	203
	200/100/0 Nomex Filling	94	98
1-F	22/1 100% 4.0 t.m. Nomex Warp	124	153
	16/1 100% 3.0 t.m. Dynel Filling	42	44
1-G	18/1 50/50 4.0 t.m. Nomex/FR Rayon Warp	116	114
	18/1 50/50 3.0 t.m. Nomex/FR Rayon Filling	33	36
1-H	18/1 50/50 4.0 t.m. Nomex/cotton Warp	88	87
	18/1 50/50 3.0 t.m. Nomex/cotton Filling	52	55
1-J	450-1/0 3Z Beta and 40/1 Nomex Warp	84	86
	450-1/0 3Z Beta and 40/1 Nomex Filling	80	78
2-A	22/1 100% Nomex 3.5 t.m. Warp	124	122
	22/1 100% Nomex 3.5 t.m. Filling	44.5	43
2-B	22/1 100% Nomex 3.5 t.m. Warp	124	140
	18/1 100% Dynel Type 183 3.0 t.m. Filling	43	43
2-C	200/100/3Z Nomex Warp	95	96
	200/100/0 Nomex Filling	60	61
2-D	22/1 100% Nomex 3 t.m. Warp	123	136
	22/1 100% PFR Rayon 3 t.m. Filling	60	59
2-E	200/100/3Z Nomex Warp	200	204
	200/100/0 Nomex Filling	94	95
3	200/100/3Z Nomex Warp	94	96
	200/100/0 Nomex Filling	61	62

4. <u>Breaking Strength</u>[1]

Breaking strength on both greige and finished fabrics was tested in accordance with Method 5100. The testing device used was a Scott, Model J-4, tensile tester, with a jaw separation rate of 12 inches per minute. The two-layer, 100 per cent filament Nomex fabrics were too strong to be broken by this testing machine in either direction. The breaking strength is estimated to be approximately 650 pounds in the warp and 400 pounds in the filling.

5. <u>Tearing Strength</u>[2]

Greige and finished samples of all fabrics were tested in accordance with Test Method 5132. This testing was done on an Elmendorf Tearing Tester rated at 6400 grams capacity. This was the highest capacity tester available for the contract.

Several of the samples were beyond the capacity of the testing machine. A large number of jaw breaks or tears were noted, especially those fabrics with uneven constructions.

A marked reduction in the tear strength of both warp and the filling of the Nomex/cotton fabric was observed. This can be directly attributed to the application of the THPC finish.

6. <u>Color Fastness to Light</u>

The color fastness to light of the 100 per cent Nomex fabrics as well as of the various blends of fabrics was noted to be poor. This is characteristic of the present fiber and not of the dyestuff. E. I. duPont de Nemours Co., Inc. is actively endeavoring to improve the lightfastness properties.

7. <u>Miscellaneous Tests</u>

Other tests to compare properties of materials or to establish certain fabric design criteria were used at the discretion of the project director and are briefly described below. Not all tests were used on every fabric.

a. Water resistance-Spray Method. Test Method 5526, a simple spray test for fabrics with hydrophobic finishes, was used to determine the completeness of the water-repellent treatments. Each

1/ Table XVI

2/ Table XVII

finished sample submitted to the U. S. Army Natick Laboratories was tested and all, with the exception of the Nomex/Beta fabric, exhibited spray ratings from 90-100.

TABLE XVI

BREAKING STRENGTH - POUNDS
(METHOD 5100 - GRAB METHOD)

Item	Description		Greige	Finished
1-A	Single-layer filament Nomex	Warp	337	349
		Filling	187	190
1-B	Filament Nomex warp/Dynel fill	Warp	314	362
		Filling	128	134
1-C	50/50 blended Nomex/Dynel	Warp	121	169
		Filling	107	140
1-D	Single-layer staple Nomex	Warp	314	340
		Filling	99	98
1-E	Two-layer filament Nomex	Warp	670[1]	650[1]
		Filling	360	384
1-F	Staple Nomex warp/Dynel fill	Warp	277	326
		Filling	73	108
1-G	50/50 blended Nomex/FR Rayon	Warp	207	191
		Filling	54	48
1-H	50/50 blended Nomex/cotton	Warp	133	136
		Filling	79	75
1-J	Beta/Nomex	Warp	162	160
		Filling	149	136
2-A	Staple Nomex Oxford	Warp	350	324
		Filling	88	90
2-B	Ortho Nomex warp/Dynel fill	Warp	260	290
		Filling	62	72
2-C	Single-layer filament Nomex	Warp	325	348
		Filling	216	206
2-D	Ortho Nomex warp PFR Rayon fill	Warp	282	272
		Filling	64	64
2-E	Two-layer filament Nomex	Warp	710[1]	768[1]
		Filling	414[1]	418[1]
3	Single-layer filament Nomex	Warp	287	299
		Filling	170	182

[1] NLABS Data

TABLE XVII

TEARING STRENGTH - POUNDS
(METHOD 5132 - PENDULUM METHOD)

Item	Description		Greige	Finished
1-A	Single-layer filament Nomex	Warp	38.6 1/	34.4 1/
		Filling	11.3	11.4
1-B	Filament Nomex warp/Dynel fill	Warp	C.T. 2/	C.T. 2/
		Filling	6.3	4.3
1-C	50/50 blended Nomex/Dynel	Warp	4.4	5.5
		Filling	4.3	4.5
1-D	Single-layer staple Nomex	Warp	8.1	8.6
		Filling	6.1	6.3
1-E	Two-layer filament Nomex	Warp	C.T.	55.+ 3/
		Filling	35.5 1/	34.2 1/
1-F	Staple Nomex warp/Dynel fill	Warp	C.T.	C.T.
		Filling	4.8	5.5
1-G	50/50 blended Nomex/FR Rayon	Warp	C.T.	C.T.
		Filling	4.8	8.2
1-H	50/50 blended Nomex/cotton	Warp	7.8	4.7
		Filling	5.2	2.8
1-J	Beta/Nomex blend	Warp	13.6	11.7
		Filling	15.6	11.7
2-A	Staple Nomex Oxford	Warp	C.T.	C.T.
		Filling	6.25	6.20
2-B	Ortho Nomex Warp Dynel fill	Warp	C.T.	C.T.
		Filling	3.17	2.0
2-C	Single-layer filament Nomex	Warp	14.0	13.0
		Filling	14.0	11.0
2-D	Ortho Nomex Warp PFR Rayon fill	Warp	3.0 1/	3.0 1/
		Filling	3.4	2.4
2-E	Two-layer filament Nomex	Warp	55.+ 3/	55.+ 3/
		Filling	55.+ 3/	55.+ 3/
3	Single-layer filament Nomex	Warp	35.7 1/	23.2 1/
		Filling	23.5 1/	11.0

1/ NLABS Data.

2/ C.T. denotes cross tears. Valid warp.
Tears could not be obtained since the fabric tears across the weakest set of yarns (filling).

3/ Maximum capabilities of machine, 55 pounds. (NLABS Data)

b. Shrinkage in Finishing. On those fabrics designed to shrink, tests were conducted in Phase I to determine the degree of shrinkage. Marks were placed 10 inches apart on each fabric in the warp and filling directions. Table XVIII lists the shrinkage in warp and filling. Area shrinkage is also calculated.

TABLE XVIII

SHRINKAGE IN FINISHING - PER CENT
(KNOWN DIMENSION METHOD)

Item	Description	Warp (1)	Fill (2)	Area Shrinkage (3)
1-B	Filament Nomex warp/Dynel fill	5.0	22.5	26.5
1-C	50/50 blended Nomex/Dynel	16.0	12.0	25.0
1-F	Staple Nomex warp/Dynel fill	5.0	18.8	23.0

$$(1) \;\&\; (2) = \frac{L_1\ (W_1) \ - \ L_2\ (W_2)}{L_1\ (W_1)} \times 100$$

$$(3) = \frac{(L_1 \times W_1) - (L_2 \times W_2)}{(L_1 \times W_1)}$$

Where: L_1 & W_1 = Dimension in greige

L_2 & W_2 = Dimension, finished

c. Thickness Test.[1] When the problem of closing the Nomex/Dynel materials was encountered, fabric thicknesses were checked. The Dynel was shrinking; however, the Nomex was not, therefore, creating a bulky fabric. An increase in thickness was also realized between the greige and finished ortho blend fabrics of Nomex and Dynel.

[1] Table XIX

TABLE XIX

THICKNESS CHANGE IN FINISHING
(METHOD 5030 - DEAD WEIGHT GAGE)

Item	Description	Greige	Finished	Per Cent Increase Thickness
1-B	Filament Nomex warp/Dynel fill	0.015	0.018	20.0
1-C	50/50 blended Nomex/Dynel	0.024	0.032	33.2
1-F	Staple Nomex warp/Dynel fill	0.021	0.026	23.8

d. Rain Room Tests. The performance of the fabrics in the rain room was the deciding test for acceptance. The U. S. Army Natick Laboratories performed these tests on the fabrics submitted. They were subjected to simulated rainfall at the rate of 1 inch of rain per hour.

Table XX lists the samples, with their performances as received before and after five launderings. Item 2C, which was the re-designed, single-layer filament with the combination finish, performed up to the requirements and was selected for production. However, the design objectives realized with Item 2C were not duplicated when scaling-up to full-scale commercial production. Specifically, the rain room performance of the finally delivered fabric (Sample No. 3) did not meet the required minimum rain room protection of 8 hours at one-inch per hour of rainfall.

TABLE XX

RAIN ROOM PERFORMANCE
HOURS
(1 INCH PER HOUR OF RAINFALL)

Sample No.	Description	As Received	After 5[1/] Launderings
1-A	Single-layer filament Nomex	2	1
1-B	Filament Nomex warp/Dynel fill	2-1/2	3
1-C	50/50 blended Nomex/Dynel	1/3	1
1-D	Single-layer staple Nomex	1	3/4
1-E	Two-layer filament Nomex	2	2
1-F	Staple Nomex warp/Dynel fill	2	2
1-G	50/50 blended Nomex/FR Rayon	1/4	1/2
1-H	50/50 blended Nomex/cotton	2-1/2	1-1/4
1-J	Beta/Nomex	.10	--
2-A	Staple Nomex oxford	2-1/2	4
2-B	Ortho Nomex warp Dynel fill	3	4
2-C	Single-layer filament Nomex	9	9
2-D	Ortho Nomex warp PFR Rayon fill	4	1/2
2-E	Two-layer filament Nomex	3-1/2	1-1/4
3	Single-layer filament Nomex	1-1/2	1

[1/] Test Method 5556 of CCC-T-191 (Cotton Procedure).

e. Flame Resistance Tests. The after-flame characteristics of all the fabrics submitted were evaluated by the U. S. Army Natick Laboratories using the Vertical Bunsen test. (Method 5903-T of CCC-T-191.)

Table XXI lists the submitted fabric samples as well as their after-flame characteristics. Because of the time element, most of the samples were screened for their after-flame potential by testing them in the finished ("as received") condition. However, the ultimate fabric delivered in quantity (Sample No. 3) was tested before and after 15 launderings and the after-flame characteristics conformed to the objectives of this program.

TABLE XXI

FLAME RESISTANCE 1/

Item	Description of Fabric	After Flame (sec.)	After Glow (sec.)	Char Length (inches)
1-A	Single-layer filament Nomex	0 x 0	11 x 14	3.1 x 3.3
1-B	Filament Nomex warp/Dynel fill	8.3 x 0.0	-	8.5 x 3.7
1-C	50/50 blended Nomex/Dynel	0 x 0	-	2.9 x 3.2
1-D	Single-layer staple Nomex	0 x 0	-	3.0 x 2.7
1-E	Two-layer filament Nomex	0 x 0	-	2.6 x 2.2
1-F	Staple Nomex warp/Dynel fill	0 x 0	-	6.2 x 3.1
1-G	50/50 blend Nomex/FR Rayon	0 x 0	-	3.5 x 2.6
		26 x 13 2/		9.2 x 5.8 2/
1-H	50/50 blend Nomex/Cotton	0 x 0	-	2.3 x 2.2
1-J	Beta Glass/Nomex	0 x 0	-	0.1 x 0.1
2-A	Staple Nomex Oxford	0 x 2	25 x 20	4.1 x 5.4
2-B	Ortho Nomex warp/Dynel fill	0 x 19 4/	24 x 2	7.9 x 7.1
2-C	Single-layer filament Nomex	0.4 x 0	12 x 19	3.9 x 4.4
2-D	Ortho Nomex warp/PFR Rayon fill	0 x 0	0 x 0	6.4 x 2.4
		0 x 0 3,4/	0 x 0 3/	7.2 x 2.5 3/
2-E	Two-layer filament Nomex	0 x 0	17 x 19	2.4 x 3.0
3	Single-layer filament Nomex	0.8 x 0	11 x 14	4.4 x 4.0
		0 x 0 2/	13 x 15 2/	3.8 x 4.0 2/

1/ Results are shown for fabrics as received in the finished state, except as noted. Results shown are for warp x filling.

2/ Results after 15 cotton mobile launderings (Method 5556 of CCC-T-191).

3/ Results after 5 cotton mobile launderings (Method 5556 of CCC-T-191).

4/ One specimen in each fabric burned completely; remaining four specimens showed 0 second after-flame.

CONCLUSIONS

Based upon the results of the experiments reported, and the physical properties of fabrics submitted to the U. S. Army Natick Laboratories, the following conclusions can be made:

(1) Intimate blending is the most versatile and economical method found for combining Nomex with other fibers.

(2) The yarn spinning problems experienced with flame-retardant rayon were directly related to fiber surface characteristics, which have since been improved by the manufacturer.

(3) Roving blending can be used as a substitute for intimate blending, provided the blend level is 50/50 and uniform dispersion of each fiber is not important.

(4) Core Spinning cannot be used to produce a yarn with a blend level of 50/50.

(5) Continuous filament Nomex can be most successfully down-twisted to 3 turns per inch (t.p.i.) with "0" tension applied to the untwisted yarn.

(6) A lightweight (under 5 ounces/yard^2), low permeability (under 10 ft.^{3}/ft.^{2}/min.), water-repellent (one inch per hour rainfall for 8 hours) fabric with after-flame characteristics of less than two seconds was produced from continuous filament Nomex using small-scale production facilities. Translation of these fabric parameters from laboratory to commercial practice was not realized in one important aspect, namely, rain protection.

(7) Ortho blend Nomex/Dynel fabrics show not only low air permeability, but also unbalanced tensile properties.

(8) Plied spun yarns should not be used in constructing lightweight, low porosity fabrics.

(9) Oxford weave (2 x 1) has produced the lowest air permeabilities of all weaves evaluated.

(10) Staple fabrics of the construction required to meet the design objectives, must be woven in a "Duck" type loom.

(11) Blending (intimate or roving) a "high shrink" fiber with Nomex creates a bulking as well as a shrinking effect and nullifies any expected reduction in air permeability.

(12) Two-layer intimately bound filament Nomex fabrics are feasible, but more work is required to perfect the concept.

(13) THPC, flame-retardant and water-repellent treatments are compatible for use on fabrics containing cotton.

(14) Combined anti-static and water-repellent treatments, used for Phase II and Phase III, are compatible on commercial finishing equipment.

RECOMMENDATIONS

Certain areas that were not completely explored in this study should be given further consideration as follows:

(1) A program should be established to further characterize the limitations and advantages to be found in the core-spinning concept of blending.

(2) Staple fabric using low-twist, tow-spun, 100 per cent Nomex yarns for maximum fabric closure in constructions and weaves that will improve on the oxford fabrics should be investigated.

(3) Twist level, warp sizing, construction and weave variations to improve on the performance of the two-layer filament fabrics should be explored.

(4) Finishing procedures to provide adequate water resistance to filament Nomex fabrics should be investigated.

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13. ABSTRACT

A three-phase program with the ultimate objective of developing a lightweight, flame-resistant, water-repellent, finished fabric is reported. A continuous filament Nomex fabric meeting all the design objectives was selected from 14 conceptual samples.

Phase I included an investigation of fibrous materials, a comparison of yarn blending techniques, fabric design and development of single and double layered prototypes, and physical testing of each sample submitted.

Phase II involved refining constructions and process details and applying a revised finishing procedure on all materials submitted. Commercial scale-up of the first prototypes was also an objective.

Phase III comprised the weaving and finishing of 1,000 square yards of the selected continuous filament Nomex fabric on a commercial production basis. Final evaluation of the filament Nomex fabric revealed that all of the design objectives were realized when converting from small to large-scale production except for providing the desired water resistance protection.

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Colorfastness	8,9					
Lightweight	0					
Fabrics	9					
Polyamide resins	9					
Nomex	9					